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CIRCUMCEREBRAL APPLICATION OF WEAK COMPLEX MAGNETIC FIELDS WITH DERIVATIVES AND CHANGES IN ELECTROENCEPHALOGRAPHIC POWER SPECTRA WITHIN THE THETA RANGE: IMPLICATIONS FOR STATES OF CONSCIOUSNESS[1]

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Summary.—Relative power within the delta, theta, low-alpha, high-alpha, and gamma electroencephalographic spectra of 8 human volunteers was recorded over the left and right frontal, temporal, parietal, and occipital lobes during and after the circumcerebral application through an array of 8 solenoids of 6 different configurations of weak (5 to 10 microTesla) magnetic fields. The solenoids were equally spaced around the subject's head along a horizontal plane above the ears. An approximately 30% increase in power within the theta band occurred transcerebrally during the application of a specific configuration, previously shown to affect subjective time, involving 20-msec. rates of change in the duration of delivery of the magnetic fields to each successive solenoid. Compared to the left hemisphere, the right hemisphere displayed a 20% increase in power within the 5.0- to 5.9-Hz range for all 6 configurations. The results suggest that very complex magnetic fields with the appropriate temporal parameters rotated around and within brain space can interact with the cerebral processes, measured as specific bands of frequencies, generating consciousness. Implications for the roles of hippocampal theta activity, cortical resonance, and Goldstone bosons in these processes are discussed.

The electromagnetic correlates of human consciousness have been inferred primarily by electroencephalographic measurements and their correlations with subjective reports. The search for a temporal binding factor that integrates the dynamic processes throughout the topological space of the cerebral cortices, a presumed prerequisite for human consciousness, has implicated the importance of 20- to 25-msec. increments in the creation of this process (Edelman, 1989). Llinas and Pare (1991) have reported that cohesive phase shifts with durations of about 20 msec. are generated continuously from a rostral to caudal direction over large areas of the cerebral cortices particularly during waking and dream states.

We have pursued the concept that direct experimental interaction with consciousness by electromagnetic fields should be more dependent upon the complimentary complexity of the applied fields rather than their intensity.

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Cook, Koren, and Persinger (1999) found that the application of circumcerebral magnetic fields in a counterclockwise direction (but not the clockwise direction) induced significant distortion in the subjective experience of time. In that study 8 solenoids were equally spaced within the horizontal plane around the subject's head. Between the first and eighth solenoid, the duration of induction of the complex fields between each successive pair of solenoids was increased by 20 msec. in the counterclockwise direction.

Our rationale for applying the circumcerebral, rotating, complex magnetic fields is derived from the concept that increased complexity (Tononi & Edelman, 1998) creates the condition for the production of information density that is sufficient to be meaningful to the brain. By applying this spatial and temporal complexity around and within the volume occupied by the brain, the density and degrees of freedom of information are expected to increase remarkably.

The physical metaphor for the basis of this interaction is that very weak magnetic fields with complexity have a greater potential for interacting with the very fast but very weak changing processes within the brain. In contrast, the static presentation in homogeneous space of a symmetrical magnetic field, such as a sine wave, should have minimal degrees of freedom. When these fields are presented in the mTesla range or at higher intensities there is a coercion towards homogeneity of response such that the complex systems are either no longer resonant or collapse and only the most simple systems are affected.

The difference between the two approaches would be analogous to redirecting a moving object by the brief application of a strategically timed force compared to stopping a moving object abruptly with a comparably intense impediment. The first example requires little energy and interacts with the momentum of the system. If this same energy also affects or determines the organizing structure of the system, then the system could be completely reconfigured. The second example involves direct interaction with each unit of the system and the exchange of substantial energies.

To discern if the applied fields from the Cook, *et al.* study (1999) were sufficient to affect the power spectra of electroencephalographic activity, we exposed normal volunteers to these same fields while electroencephalographic activity was recorded by computer. Persinger (1999) had calculated that derivatives or changes in frequency shifts in the electroencephalographic frequencies around 6 Hz would involve increments of 20 to 25 msec. We predicted that, if the circumcerebral fields responsible for inducing the alterations in subjective time were affecting these processes, the largest changes in the power spectra should occur within the theta (4 Hz to 7 Hz) frequency band within which the derivatives would be generated. On the other hand, if the changes associated with consciousness were specific to the peri-

ods of 20 msec. to 25 msec. occupied by each first-order or primary cycle within the 40- to 50-Hz band as assumed by many contemporary researchers (Jeffreys, Traub, & Whittington, 1996; Thatcher, 1997), the field-induced alterations should occur predominantly and more powerfully within the gamma range.

Method

Subjects

Four men and four women, between 21 and 30 years of age, volunteered as subjects. All subjects were university students.

Equipment

The magnetic fields were generated by the "Octopus," an array of eight pairs of solenoids equally placed around the scalp in the horizontal plane just above the ears and approximate to the epicanthal-meatal line. Each of the eight canisters contained two solenoids that generated magnetic fields, at the scalp level, with strengths between 5 microTesla and 10 microTesla. The canisters were adhered to the scalp by velcro patches that were attached to a band of velcro placed comfortably around the scalp. A diagram of the arrangement has been published elsewhere (Cook, *et al.*, 1999).

The counterclockwise direction of the patterns began over the left prefrontal region and ended in the right prefrontal region. A 286 laptop computer generated and controlled the configuration of the magnetic fields. Configurations were defined as the temporal values that controlled the patterns, their timing, and the parameters of the rotation of these patterns around the head. The shapes of the two patterns employed in this study were generated by transducing a series of numbers between 0 and 255 (where 0 polarity is 127, negative polarity is less than 127, and positive polarity is greater than 127), which corresponded to –5 V or +5 V, by a digital to analogue converter to magnetic fields.

There were five parameters. Pixel duration referred to the real time for the generation of the graded voltage represented by each number (point) between 0 and 255 as the software progressed through the number files (containing values between 0 and 255) that created the patterns. For example, if the pixel duration was 1 msec. and there were 200 lines each containing a number between 0 and 255, the total time for the execution of the file and the generation of the pattern once would be 200 msec.

Interstimulus duration was the time between the presentation of each pattern. A duration of 1 msec. indicated continuous presentation while a duration of 3000 msec. indicated presentation every 3 sec. The commutator rate referred to the time the pattern was presented at each solenoid while the rate of change was the rate of change in this presentation. For example,

if the commutator rate was 100 msec. and the rate of change was –10 msec., then the duration of the field would be 100 msec. at the first solenoid, 90 at the second, 80 at the third, etc. until the cycle began again.

Procedure

After completing the consent form, each subject sat in a comfortable chair. Eight silver electrodes were attached by EC2 conductive paste on the scalp over the left and right frontal (F7, F8), temporal (T3, T4), parietal (P3, P4), and occipital (O1, O2) lobes according to the 10-20 system of measurement. The measurements were all referenced to the ear. The subject was then blindfolded and wore disposable earplugs. The primary instruction was to relax but not to fall asleep. Electroencephalographic activity verified that the level of arousal remained within Stage 0 and Stage 1; Stage 2 spindles were never observed.

Following the approximately 1 min. required to verify the functional operation of each electrode and the appropriate setting of the gain for each channel, a baseline of 20 sec. was recorded by paper and by computer. During the subsequent approximately 30 min. each subject was exposed to each of the six configurations of circumcerebral, counterclockwise rotating magnetic fields. Each configuration was presented for 5 min. followed by a period of 2 min. with no field. Twenty-sec. measurements by hard copy and by computer were completed after each field had been activated for 2.5 min. and after the field had been off for about 5 sec.

The six configurations were composed of the three phases and the two types of pulses that were identical to those employed by Cook, *et al.* (1999) to induce alterations in subjective time estimations. The parameters for the configurations are shown in Table 1. The shapes of the patterns have been published elsewhere (Persinger, Tiller, & Koren, 2000). For half the numbers of men and women the order of the configurations was B1, B2, B3, T1, T2, and T3, while for the other two men and two women the order of presentation was T3, T2, T1, B3, B2, and B1.

TABLE 1
FIELD PARAMETERS (IN MSEC.) EMPLOYED DURING APPLICATION OF COUNTERCLOCKWISE CIRCUMCEREBRAL FIELDS

Parameter	Configuration					
	1	2	3	4	5	6
	B1	B2	B3	T1	T2	T3
	Burst Pattern			Frequency-modulated		
Pixel duration	1	1	3	1	1	3
Interstimulus time	1	1	3000	1	1	3000
Commutator Rate	20	100	200	20	100	200
Change in rate	+2	+20	–2	+2	+20	–2

Electroencephalographic signals were acquired by a Grass Model 8 machine. Low pass and high pass real-time filters were set at 5 Hz and 10 kHz, respectively. The measurements were acquired from each channel by a computer at a rate of 1,000 samples per sec. using a National Instruments data acquisition card and *Labview*, a software package for acquiring data. This allowed a maximum reliable frequency of 500 Hz. Values for the raw data were represented as power within the millivolt range. The acquisition of the 20 sec. of quantitative data was completed with minimum involvement of artifacts as verified by monitoring in real time the hard copy (strip chart) measurements.

Once acquired, *Matlab*, a software package specialized for calculating matrices and vectors was implemented for filtering the data into six distinct frequency bands: delta (1 to 4 Hz), theta (4.0 to 7.9 Hz), low alpha (8.0 to 10.4 Hz), high alpha (10.5 through 13.0 Hz), beta (13.1 Hz through 20 Hz), and gamma (35 Hz through 45 Hz). On the basis of the results obtained from these analyses additional extractions were made just below, within, and just above the theta range for the six successive 1-Hz windows: 3 Hz to 3.9 Hz, 4 to 4.9 Hz, 5 to 5.9 Hz, 6 to 6.9 Hz, 7 to 7.9 Hz, and 8 to 8.9 Hz.

To minimize individual differences two measurements were employed for analyses rather than the raw scores. The relative power for each of the eight channels (two hemispheres, four lobes) for each of the six configurations was calculated by dividing the power for each frequency band while the fields were on by the baseline for each person. To discern more optimally within-lobe effects during the presentation of the six configurations, z scores were calculated for each lobe (lead) within each hemisphere. This was completed by subtracting the scores for raw power during the presentation of each of the six configurations from the mean for all six patterns and dividing this difference by the standard deviation for these values.

These two measurements were also calculated for the No (sham) Field conditions immediately after the presentation of each of the six configurations. Consequently there were files containing relative power for the No Field conditions relative to baseline and z scores for the power during the six periods of No Field following the presentation of the fields.

Because of the limits of the statistical software and to facilitate testing of our hypothesis, the main design was a five-way analysis of variance with four within-subject levels. The four within-subject levels were hemisphere (left vs right), lobe (frontal, temporal, parietal, and occipital), pulse pattern (frequency-modulated vs burst-firing), and phase (1, 2, or 3, which reflected the parameters of the rates of rotation). The independent variable was the order of the field presentations (burst-firing first or frequency-modulated first).

For the first level of the analysis the relative power and z score of the

power for each of the six frequency bands were analyzed separately. For the second level of analysis, on the basis of the results from the first level, analyses of the relative power and z scores of the power for each of the successive 1-Hz increments within the theta range were analyzed. All analyses, including *post hoc* procedures, were completed by SPSS software on a VAX 4000 computer.

Results

The results of the four-way analyses of variance for the relative power compared to baseline and for the z scores for the changes in power during the presentations of the fields are shown in Tables 2 through 5. Tables 2 and 3 refer to the results of the analyses for the relative power and z scores

TABLE 2

Percentage of Explained Variance as Indicated by Partial Eta-squared Values For Main Effects and Interactions For Relative Power of Electroencephalographic Activity Within Delta, Theta, Low-alpha, High-alpha, Low-beta, and Gamma Ranges Over Two Hemispheres and Four Lobes During Different Pulse Shapes and Phases

Source	Delta	Theta	Low Alpha	High Alpha	Low Beta	Gamma
Lobe	21	9	3	0	6	21
Hemisphere	37	22	4	11	31	3
Pulse	26	6	32	43*	14	5
Phase	17	22	14	10	3	4
Lobe × Hemisphere	18	8	21	13	32	4
Lobe × Pulse	10	4	2	6	12	10
Lobe × Phase	4	2	7	10	7	22
Hemisphere × Pulse	4	4	4	14	21	1
Hemisphere × Phase	13	33	37	29	12	3
Pulse × Phase	25	52†	25	26	33	26
Lobe × Hemisphere × Pulse	9	7	16	23	32	14
Lobe × Hemisphere × Phase	16	21	26	25	16	12
Lobe × Pulse × Phase	9	18	16	24	19	6
Hemisphere × Pulse × Phase	7	2	1	3	9	49†
Lobe × Hemisphere × Pulse × Phase	13	8	6	12	25	19

†$p < .01$.

for the power within the delta, theta, low-alpha, low-beta, and gamma ranges. Tables 4 and 5 refer to the results of the analyses for the relative power and z scores for the power within successive 1-Hz increments between 3.0 and 8.0 Hz, the band within which the primary experimental effects were observed.

Eta-squared values for the results of the analyses of variance for the measures of relative power compared to baseline and the z scores for the power changes during the presentations of the fields are shown. These par-

TABLE 3

PERCENTAGE OF EXPLAINED VARIANCE AS INDICATED BY PARTIAL ETA-SQUARED VALUES FOR MAIN EFFECTS AND INTERACTIONS FOR *z* SCORES OF POWER OF ELECTROENCEPHALOGRAPHIC ACTIVITY WITHIN DELTA, THETA, LOW-ALPHA, HIGH-ALPHA, LOW-BETA, AND GAMMA RANGES OVER TWO HEMISPHERES AND FOUR LOBES DURING DIFFERENT PULSE SHAPES AND PHASES

Source	Delta	Theta	Low Alpha	High Alpha	Low Beta	Gamma
Lobe						
Hemisphere						
Pulse	0	0	16	29	4	0
Phase	1	11	21	14	6	15
Lobe × Hemisphere						
Lobe × Pulse	11	15	4	1	7	4
Lobe × Phase	10	4	10	11	10	6
Hemisphere × Pulse	6	4	37	51*	7	4
Hemisphere × Phase	0	7	18	17	3	20
Pulse × Phase	19	54†	34*	27	36*	25
Lobe × Hemisphere × Pulse	20	4	19	26	10	11
Lobe × Hemisphere × Phase	19	18	11	12	13	13
Lobe × Pulse × Phase	10	7	17	27*	21	11
Hemisphere × Pulse × Phase	9	0	3	4	7	10
Lobe × Hemisphere × Pulse × Phase	11	34†	24	29	20	3

*$p < .05$. †$p < .01$.

TABLE 4

PERCENTAGE OF EXPLAINED VARIANCE AS INDICATED BY PARTIAL ETA-SQUARED VALUES FOR MAIN EFFECTS AND INTERACTIONS FOR RELATIVE POWER OF ELECTROENCEPHALOGRAPHIC ACTIVITY WITHIN 1-HZ BANDS BETWEEN 3 HZ AND 8 HZ (THETA RANGE) OVER TWO HEMISPHERES AND FOUR LOBES DURING DIFFERENT PULSE SHAPES AND PHASES

Source	3.0–3.9	4.0–4.9	5.0–5.9	6.0–6.9	7.0–7.9	8.0–8.9
Lobe	3	12	24	11	11	6
Hemisphere	32	27	35*	4	0	26
Pulse	0	0	3	4	6	29
Phase	7	10	17	23	16	13
Lobe × Hemisphere	4	5	10	13	3	2
Lobe × Pulse	8	11	5	34*	24	21
Lobe × Phase	14	15	13	4	7	2
Hemisphere × Pulse	13	19	3	4	0	9
Hemisphere × Phase	9	1	16	25	10	36*
Pulse × Phase	6	5	31	24	23	9
Lobe × Hemisphere × Pulse	7	3	2	7	12	19
Lobe × Hemisphere × Phase	14	8	16	4	11	19
Lobe × Pulse × Phase	15	15	6	6	4	24
Hemisphere × Pulse × Phase	18	18	1	11	3	1
Lobe × Hemisphere × Pulse × Phase	19	17	15	12	3	10

*$p < .05$.

tial eta-squared values were presented instead of F ratios because they reflect the strength of the effect. Only those effect sizes with statistical significance less than $p = .05$ are indicated by asterisks.

TABLE 5

PERCENTAGE OF EXPLAINED VARIANCE AS INDICATED BY PARTIAL ETA-SQUARED VALUES FOR MAIN EFFECTS AND INTERACTIONS FOR z SCORES OF ELECTROENCEPHALOGRAPHIC ACTIVITY DURING FIELD PRESENTATIONS WITHIN 1-HZ BANDS BETWEEN 3 HZ AND 8 HZ (THETA RANGE) OVER TWO HEMISPHERES AND FOUR LOBES DURING DIFFERENT PULSE SHAPES AND PHASES

Source	3.0–3.9	4.0–4.9	5.0–5.9	6.0–6.9	7.0–7.9	8.0–8.9
Lobe						
Hemisphere						
Pulse	13	10	3	0	6	25
Phase	1	0	4	20	32	37*
Lobe × Hemisphere						
Lobe × Pulse	12	17	10	33*	31*	38*
Lobe × Phase	15	16	9	10	3	9
Hemisphere × Pulse	1	1	15	2	22	14
Hemisphere × Phase	2	0	3	39*	12	18
Pulse × Phase	16	20	46†	18	28	43†
Lobe × Hemisphere × Pulse	10	6	22	8	20	12
Lobe × Hemisphere × Phase	19	14	13	8	9	26*
Lobe × Pulse × Phase	30†	27*	18	3	6	10
Hemisphere × Pulse × Phase	6	12	9	23	6	0
Lobe × Hemisphere × Pulse × Phase	10	6	15	10	13	17

*$p < .05$. †$p < .01$.

The most consistent and strongest effect was the statistically significant interaction between phase (1, 2, or 3) and the pattern (frequency-modulated vs burst) for power within the band. This significant interaction was evident for the measurements of relative power compared to baseline as well as within field power during the presentation of the six patterns. The results of the analyses for the measurements completed during the No Field conditions (not shown), immediately after the cessation of each of the six patterns also showed a statistically significant interaction between pattern and phase within the theta band whose partial eta-squared value was 41% for the relative power measures and 43% for the z scores.

Post hoc analyses indicated that the interaction between pattern and phase was due too the significant increase in both power relative to baseline (Fig. 1) and the z score of the within-field power when the frequency-modulated pattern was applied with a commutator rate of 100 msec. and a change in rate of 20 msec. However, the source of this interaction during the *No Field* samples was due to the increase in relative power and the z score of

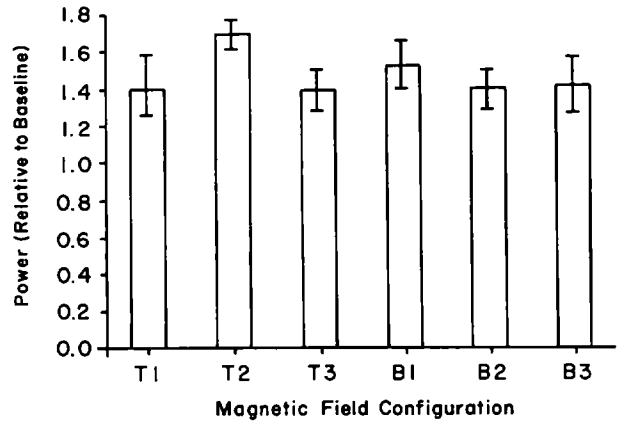

FIG. 1. Relative power compared to baseline within theta range as a function of the different patterns and phases. Vertical lines refer to standard errors of the mean.

the power within the theta range following the presentation of the burst-firing pattern when it was presented at a commutator rate of 20 msec. and a change in rate every 2 msec. (Fig. 2).

Subsequent analyses with the six 1-Hz successive increments within the theta range indicated statistically significant interactions between phase and pulse for the z-score transformations (Table 5) for the band between 5.0 Hz

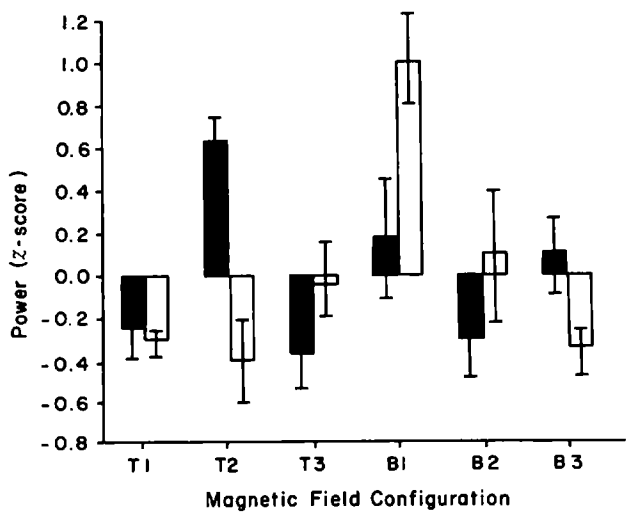

FIG. 2. z scores for changes in power within the theta band in each of the six configurations when the magnetic fields were on (■) and when they were off (□). Vertical lines refer to standard errors of the mean.

and 5.9 Hz. *Post hoc* analysis indicated that the source of this interaction was the greater increase of relative power during T2 (Configuration 5) compared to the other two phases (T1, T3) containing the frequency-modulated pulse relative to the decrease in power within this band during Phase 2 (B2) compared to the other two phases (B1, B3) containing the burst-firing pattern (Fig. 3). The results of the analyses for the relative power changes were comparable.

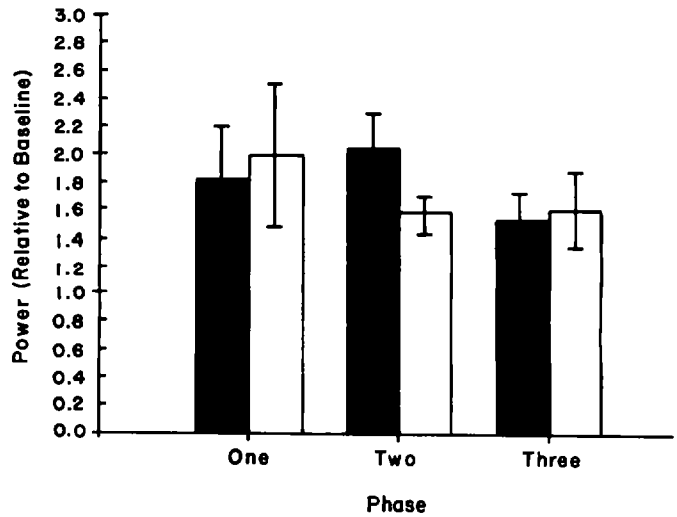

FIG. 3. The interaction between pattern [frequency-modulated (■) and burst-firing (□)] and phase for relative power compared to baseline within the 5.0-Hz to 5.9-Hz band. Standard errors of the mean are indicated by vertical lines.

Differential effects of the counterclockwise rotating circumcerebral magnetic fields upon the left and right hemispheres were noted for the 5.0-Hz to 5.9-Hz band for the relative increases in power compared to baseline. During the presentation of all six configurations, there was a significant increase in relative power generated by the right hemisphere ($M = 1.87$, $SEM = .23$) compared to the left hemisphere ($M = 1.66$, $SEM = .28$). For the z-score measures, a marked interaction between hemisphere and phase (regardless if the pattern was frequency-modulated or burst-firing) was clear. As shown in Fig. 4, this interaction was due to the significant increase in power over the right hemisphere during Phase 2 (commutator rate of 100 msec. with a change of 20 msec.) compared to the marked decrease in power during Phase 3 (T3 and B3) while these changes were not evident over the left hemisphere. In fact, the difference between the left and right hemispheres during Phase 3 was the most statistically significant effect ($t_7 = 4.25$, $p < .01$).

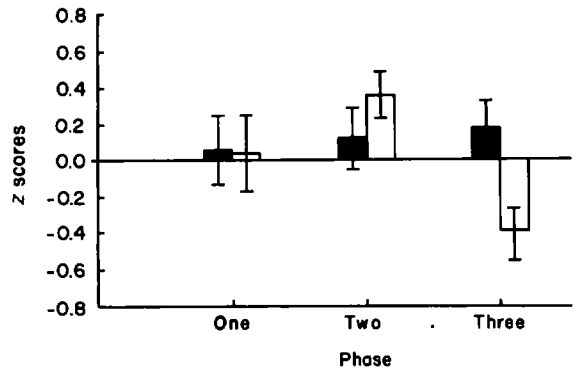

FIG. 4. The interaction between hemisphere [left (■) vs right (□)] and phase for the *z* scores for the changes in power during the three phases for power within the 6.0-Hz to 6.9-Hz band. Vertical lines indicate standard errors of the mean.

Both the measures for relative changes in power from baseline and within-field (*z* scores) changes in power showed a significant interaction between lobes and pulse within the 6.0-Hz to 6.9-Hz and 7.0-Hz to 7.9-Hz bands. The results of the *post hoc* tests for the *z* scores, which are similar to those for the relative measures, are shown in Table 6. The primary source of the interaction between lobes and pulses within the 6.0-Hz to 6.9-Hz band was due to the discrepancy in power within the occipital lobes during the application of the two different pulses. Within the 7.0-Hz to 7.9-Hz range the interaction was due to the relative absence of discrepancy of power within the occipital lobes when the two pulses were given.

TABLE 6

z SCORES FOR WITHIN-PATTERN VARIATIONS IN POWER IN SPECIFIC THETA BANDS 6.0 TO 6.9 HZ AND 7.0 TO 7.9 HZ FOR SIX CONFIGURATIONS DEMONSTRATING INTERACTION BETWEEN LOBES AND TWO PATTERNS (FREQUENCY-MODULATED AND BURST-FIRING)

Pattern	Lobe							
	Frontal		Temporal		Parietal		Occipital	
	M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
6.0 to 6.9 Hz								
Frequency-modulated	.09	.31	.07	.51	.02	.35	−.23	.44
Burst-firing	−.09	.31	−.07	.51	−.02	.35	.23	.44
7.0 to 7.9 Hz								
Frequency-modulated	.16	.36	.16	.46	.12	.49	−.04	.51
Burst-firing	−.16	.36	−.16	.36	−.12	.49	.05	.51

DISCUSSION

These results have demonstrated that the specific timing of weak, complex magnetic fields applied in a counterclockwise direction around the brain can affect the power spectra of its electroencephalographic activity. The first,

most powerful and consistent effect was the enhancement of the power within the theta range (4.0 Hz through 7.9 Hz) during the application of a frequency-modulated pattern that was induced over the left frontal solenoid for 100 msec. and was then maintained an additional 20 msec. at the next solenoid until the duration of the final presentation at the last (right frontal) solenoid was 240 msec. before the cycle began again. This produced a rate of change of 20 msec. through seven of the solenoids and a sudden reduction of 140 msec. between the eighth and first solenoid (right vs left prefrontal region) at the beginning of each cycle.

According to the estimates of effect size (partial eta-squared values), about 50% of the variance in the power within the band of theta activity was accommodated by the application of the six configurations. The change in the increase in power during the specific configuration (T2), compared to the other configurations, was equivalent to about 1 standard deviation. Compared to the baseline, the power increased by about 20% during this configuration compared to the other five. Because there were no statistically significant interactions with configurations and either hemisphere or lobe, we are assuming that the effect upon the general range of theta activity was produced homogeneously over the entire brain. Such transcerebral homogeneity might be considered a necessary condition for an emerging factor that would bind at least one level of consciousness within intracerebral space.

Cook, *et al.* (1999) found that the distortion in subjective time increased by a comparable proportion compared to the baseline (no field) condition. The presentation of these six configurations when applied in a counterclockwise direction also explained about 50% of the variance in time estimates compared to the same six configurations applied in the opposite (clockwise) direction. In the Cook, *et al.* study (1999) Configuration 5 (Phase 2, frequency-modulated pulse) was associated with a 20% to 30% increase in time estimations compared to the other five configurations. In the present study this configuration generated an approximately 20% to 30% greater power spectra within the theta band over the entire brain compared to the other configurations.

That these effects were not exclusively due to spurious inductions within the scalp electrodes was indicated by the specificity of the effect for the same configuration that has produced the strongest subjective experiences in our subjects. There were also several statistically significant interactions, accommodating 30% to 50% of the variance between hemisphere and phase of the field or among hemisphere, phase, and pattern of the field. If the effects in this study were exclusively due to current induction within the electrodes, then the differential effects over the right and left hemispheres for the different configurations would not have been likely.

Perhaps the strongest argument that the changes in power spectra were

not complex artifacts was the changes in the power spectra during the 20-sec. interval immediately after the 5 sec. following the termination of the fields. In this instance, there was a statistically significant increase in power within the theta range for Configuration 1 (half the numbers of subjects received this first while the others received it last). This configuration is known to evoke "spinning" sensations and "vortex imagery" in volunteers. In the present study, the subjects reported similar experiences. In addition to indicating that the changes in power within the theta band were not being induced by the applied fields (because they were not presented), the increased power and experiences reported during the removal of the field emphasizes the general principle of sensory systems that some aggregates of neurons respond to the presentation of stimuli while others respond to the removal of specific stimuli.

The subsequent analysis of 1-Hz increments within the theta band indicated that most of the strongest and statistically significant effects occurred within the 5.0-Hz to 5.9-Hz range for both methods of measurements (relative power and z score of the power comparisons between the fields only). The results showed that the shifts in 20 msec. around the 200-msec. duration of each solenoid produced the greatest relative increase in power during the presentation of the frequency-modulated Configuration 5 compared to the burst-firing Configuration 2.

In addition, for the relative measures, there was a general increase in power within the 5.0-Hz to 5.9-Hz range over the right hemisphere compared to the left hemisphere when *any* of the fields were being applied. The relative power was 21% higher over the right than the left ($t = 1.92$, $p < .10$) within the 5.0-Hz to 5.9-Hz range. In comparison, the relative increases within the 6.0-Hz to 6.9-Hz, 7.0-Hz to 7.9-Hz, and 8.0-Hz to 8.9-Hz ranges, were 4%, 0%, and 8%, respectively. For the 3.0-Hz to 3.9-Hz and 4.0-Hz to 4.9-Hz ranges, these values were 12% and 14%, respectively. This hemispheric asymmetry suggests that the gestalt of the field generated by the array's counterclockwise direction preferentially affected this narrow band of cerebral activity over the right hemisphere compared to the left.

The hemispheric differences in power within the theta range were also responsive to the duration of the field at each solenoid and its change in rate around the array. There was an increase in power over the right hemisphere compared to the left within the 6.0-Hz to 6.9-Hz band during the presentation of either pattern when the time at each solenoid was 100 msec. and the change was 20 msec. On the other hand, there was a decrease in power during the field presentation within the right hemisphere compared to the left during the presentation of either pulse when the time at each solenoid was 200 msec. and the change was –2 msec. These differences suggest that the configuration was important. Theoretically, Phase 1 would have in-

duced the greatest artifact because it contained the most frequent changes in intensity per unit time. However, it did not induce any hemispheric discrepancy. The absence of this effect also minimizes the likelihood that the statistically significant observations were due to spurious interactions between the electrodes and the applied fields.

Enhanced power within theta bands has been classically associated with hypnagogic imagery and imaginal processes, including those associated with hypnosis (Kavanau, 1996). Increases in the power of cortical theta oscillations have been associated with human spatial navigation and cognition (Kahana, Sekuler, Caplan, Kirschen, & Madsen, 1999). Recently, Klimesch, Doppelmayr, Stadler, Poellhuber, Sauseng, and Roehm (2001) found an approximately 26% increase in theta power during retrieval of episodic memory. These general correlates of increased theta activity would be consistent with processes that involve subjective navigation through imaginal space as well as when and where (episodic memory) this navigation occurred.

Theta oscillations within the hippocampus are associated with a rat's position in space and may reflect the brain's representations of spatial configurations relative to the "observer" or the computational system's reference point (Louie & Wilson, 2001). Whether or not the hippocampal formation is the solitary source of cortical theta activity requires further investigation. The mechanism by which the increased power within the theta band occurred cannot be discerned by our experimental design. However, a direct effect upon the hippocampal system and the neuronal patterns responsible for the experiences of recollection by the applied fields would be one candidate. Exposure to theta-burst patterned magnetic fields rotated systematically through each of the planes of space and then generated simultaneously in all three dimensions can affect the memory for context and spatial patterns in rodents (McKay & Persinger, 2000; McKay, Persinger, & Koren, 2000).

Alternatively, the spatial geometry of the solenoids and the temporal patterns of the applied fields may have satisfied the conditions to generate neocortical resonances between the surface of the cerebral manifold and the band of solenoids. This might be considered similar to the three concentric rings of space that constitute the ionosphere, biosphere, and crust of the earth which allows the generation of the 6-Hz to 8-Hz Schumann resonance and its harmonics. The most common solution to one of Maxwell's equations for the resonant cavity in the spherical geometry predicts mode frequencies of an electromagnetic field that can be defined by the product of the square root of $n(n+1)$ and the ratio of c/r divided by 6.28 (2 pi) where $n = 1, 2, 3$, etc., c is the velocity of the process through space and r is the radius of the spherical structure.

As cleverly integrated by Nunez (1995), the cerebral equivalent of the values for the speed of light (c) and the radius (r) of the earth that describes

the frequencies of the Schumann resonance would be between 6 and 9 m/sec., for the velocity of propagation of corticortical action potentials and between 11 and 18 cm for the radius of cerebral volume. An *r* of 20 cm and a central speed of 6 m/sec. would exhibit a first-order modal frequency of about 6 Hz. It would be of significant theoretical and practical interest if the increased power within the theta band over the right hemisphere observed in this study reflected standing waves due to the interference between the rostrocaudal movement of the phase shifts reported by Llinas and Pare (1991) and the caudal-to-rostral derivatives over the right hemisphere during counterclockwise rotations of the fields.

Edelman (1989) hypothesized that re-entrant processes within the timeframe of about 20 to 25 msec. (45 Hz to 40 Hz) generate higher orders of organization and complexity that create higher-order consciousness (Tononi & Edelman, 1998). Persinger (1999) suggested that shifts in power within very narrow band-widths between 5 Hz and 6 Hz might serve as a binding factor for human consciousness and that more than one source may exist. These values were obtained by computing the differences in real time between the duration of two adjacent integer frequencies such as 6 Hz and 5 Hz and the shifts in those values. This procedure was analogous to obtaining derivatives or phase shifts in fundamental frequencies without changing their specific morphology or timing.

In the present study the component of the theta band that displayed the greatest increase in power during the application of the fields was within the 5.0- to 5.9-Hz increment (1 Hz was our smallest increment of analysis). Although this concordance may have been coincidence and does not prove the existence of a binding factor within the higher-order derivatives created within this narrow range, the results suggest that the weak complex magnetic fields may have interacted directly with the processes that created the enhanced power. If the hypothesis (Persinger, 1999) is valid, then a qualitatively different type of consciousness may have been generated within the brains of the experients because the binding factor would have been enhanced within this particular domain.

We did not find any robust statistically significant effects, defined as main effects with phase or pattern or interactions between these levels and either lobe or hemisphere within the gamma range. This range has been considered the most likely candidate for the binding factor for consciousness (Edelman, 1989; Crick & Koch, 1990; Llinas & Pare, 1991). There was a four-way interaction among hemisphere, phase, and pattern within the gamma range. *Post hoc* analyses indicated that the interaction was due primarily to the increased power during the T2 relative to the B2 field and increased power during the B1 compared to the T1 fields over the right hemisphere. This difference was not recorded over the left hemisphere. In-

stead, all but Configuration 6 showed relatively less power. The meaning of this complicated interaction is not clear.

If the appropriate temporal parameters are applied, direct interaction with the complexity of processes that either create or are associated with various forms of consciousness should occur with extraordinarily weak electromagnetic fields. We are examining the feasibility of testing empirically the theoretical concepts of Jibu and Yasue (1995). They have indicated that quantum brain dynamics penetrate into the spatial dimensions occupied by neurons and produce a variety of fields of consciousness where Goldstone bosons can be created. The Goldstone boson, whose mass is zero and energy eigenvalues approach zero, can be created within macroscopic domains of an ordered state by receiving any small amount of energy.

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